Stirring Up Undergraduate Interest in Relativity Research in a Non-relativistic Department

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Abstract

Simply offering an advanced relativity course is sufficient to stir up interest in relativity research at University of Central Florida. This paper describes my experience teaching special and general relativity at UCF in spring semester, 2003. I conclude with a few ideas and questions about GR curriculum innovation, especially in support of further LIGO research.

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1. INTRODUCTION

UCF is a large public university in Orlando, with high research activity, high undergraduate enrollment, and a comprehensive doctoral program[1]. Enrollment in fall 2005 was 45,090. In spring 2006 there were 78 physics majors. The physics faculty is dominated by nanophysics experimentalists.

In October of 2002, the department asked me to put together a relativity course for undergraduate physics majors, to begin in January of 2003. We taught it as an *ad hoc* "special topics" course; 16 students enrolled and 13 finished the semester. The plan was to teach some advanced features of special relativity and some elementary features of general relativity. The prerequisite was our PHY3323 Electricity and Magnetism I course, so that the students would have a solid grasp of Maxwell's equations.

I chose the Ellis textbook [2] for this class, since its content did include both special and general relativity, and because it had sufficient mathematical rigor in its appendices. Although the Hartle textbook [3] came out too late to adopt for our 2003 course, I did use it extensively as a supplement and aid.

My plan was to divide the semester in two: build the special relativity half of the course toward a study the electromagnetic field tensor, and thereby lead gracefully to other tensors required in the GR half of the course. To save time, I also planned to bypass the development of most of the mathematical tools, knowing that students could walk through the mathematical development later in their academic work.

Our department is full of nanophysics experimentalists, so faculty-student interaction seldom inspires the ability to think four-dimensionally. For this reason, I made specific plans to teach about four-vectors. Also, I realized that students would be thinking of the Lorentz transformation merely as an interesting set of equations that one must use for high speed physics. To boost them out of that state, I also planned to teach the geometric nature of the Lorentz transformation, as a unimodular spacetime "rotation"

$$\begin{bmatrix} \gamma & \gamma\beta & 0 & 0 \\ \gamma\beta & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cosh(\eta) & \sinh(\eta) & 0 & 0 \\ \sinh(\eta) & \cosh(\eta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

with rapidity η, a transformation which we compared to a purely spatial rotation. I concluded the first half of the course with thought experiments that lead to grappling with the electromagnetic field tensor.

For the GR half of the semester, my plan was to show how to map out light cones and compute redshifts in the Schwarzschild spacetime and discover their meaning. We did not derive the metric. We finished with the standard end-of-semester dash through the remaining material: Robertson-Walker cosmological models and the Hubble equation.

Student word-of-mouth spread quite rapidly as soon as I agreed to teach the course. Enrollment was excellent, and the few students who dropped before the end of the semester did so because they could not swing their schedules to take my course. Enthusiasm was excellent. A few learned to think four-dimensionally. Many students expressed interest in further relativity study and research.

2. TROUBLE

Despite a good, modest plan, various troubles arose. The university's registration software did not trap the prerequisite, so only five of the 17 students who enrolled had taken Electricity and Magnetism I. The result was a motley array of physics and mathematical experience. However, making a virtue of necessity, we covered a few more elementary concepts and paradoxes of special relativity, such as Wald's introductory car and garage problem [4].

Another difficulty arose from UCF's incredibly rapid growth in enrollment: to 45,090 in 2005 from 20,089 in 1989. Compounding this is the university's long term strategy to upgrade itself to a top national research university from its initial status as an undergraduate teaching institution. As a result, teaching assignments can display nonlinear dynamical effects, one of which was the double overload I carried in spring semester 2003, and the crash preparation of this relativity course. As of 2006, however, prospects for steadying the GR curriculum are good.

3. DISCUSSION

For the next evolution of UCF relativity teaching, we plan to implement prerequisites strictly. Due to Florida curriculum development constraints, however, it will be 2009 or later before UCF moves relativity from "special topics" mode to a normally numbered course.

We will adopt the Hartle textbook.

Now I will share some questions. My institution is not active in LIGO research, but I would like to send well-prepared students to work with active LIGO researchers. How do I adjust my course to effect a good export? What extramural programs exist, e.g., summer schools, to which I can send an undergraduate?

Course materials also concern me. Would the advanced latter section of a textbook like Hartle's be useful for independent study after the semester-length course I have described? If so, would it be sufficient preparation for actual research activity as Baumgarte[5] and others have described? Specifically, would such a use of that textbook be sufficient preparation for LIGO research experience for an undergraduate?

I frequently use the journal Nature with my undergraduates, because it publishes lower level "news features" that point to technical letters and articles in the same edition. Does the LIGO project have a plan to publish articles at the level of "news features" in broad spectrum publications like Nature, timely articles that are comprehensible to undergraduates?

My principal teaching task in UCF is large enrollment introductory physical science courses. In the 2005-2006 academic year, I taught 1058 students. How can I incorporate LIGO and GPS concepts gracefully into this curriculum?

I also teach online physics courses in UCF. Is it possible to develop a central or standardized online teaching and assessment environment that helps prepare undergraduates for LIGO and other GR research experience?

Finally, I have a strong inclination to teach as much as I can visually and to teach students to become as powerful as possible with the visualization of their ideas. My thought is that teaching scientific visualization should begin in first semester, first year. However, by the time they are taking a GR course in their junior or senior year, how much visualization can we expect from students?

It is my hope that participation in this AAPT/LIGO topical conference will help me find answers to these questions. I would like to thank Lee Chow for steady, encouraging assistance at UCF.

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[1] Carnegie Foundation for the Advancement of Teaching, Carnegie Classifications Data File, July 7, 2006 edition.

[2] G.F.R. Ellis and R.M. Williams, *Flat and Curved Space-Times, 2nd ed.*, Oxford University Press, 2001.

[3] James B. Hartle, *Gravity: An Introduction to Einstein's General Relativity*, Addison Wesley, 2003.

[4] R.M. Wald, *General Relativity*, University of Chicago Press, 1984.

[5] Thomas W. Baumgarte, "Some Thoughts on Involving Undergraduate Students in GR-Related Research." AAPT Topical Conference - Teaching General Relativity to Undergraduate, 2006.